INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.12, NO.1, JANUARY 2017

A Novel Microstrip Low Pass Filter Based on Ring Topology

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***Abstract*- This paper describes the design of a new configuration of a low pass filter (LPF). This filter structure is based on a ring topology. The proposed LPF is miniature and low cost because it is mounted on FR4 substrate. The validation of this circuit into simulation was based on many optimization methods integrated in ADS "Advanced Design System" and some tuning methods. At the end, the fabrication and the test of the final circuit permits to have a good agreement between simulation and measurement results reaching a low pass behavior. The proposed filter has an area of 25x25 mm^2, with a cutoff frequency of 2GHz and good performances in term of insertion losses, which are around -0.127 dB in the whole bandwidth and a high stopband.**

***Index Terms*- microstrip, planar filters, low pass filter, DCS, ISM.**

I. INTRODUCTION

RF filters have been widely studied and employed extensively as key components in modern communication systems. Known, as two port devices this kind of circuit is exploited to suppress unwanted signals and to separate signals of different frequencies. Most of telecommunication systems require numerous kind filters, microwave receivers and transmitters for example needs filters for a preselection function such as the case of a receiver front end. They are also utilized to suppress noise produced by mixers and parasitic signals generated by power amplifier in transmitter. In addition, filters provide access to the passband and stop band characteristics in diplexer and multiplexers.

Theoretically, an ideal filter lets pass all desired frequencies with no attenuation and no shift and rejects all the unwanted frequency bands. The design of a microwave filter begins by the approximation of its ideal response by a finite-order polynomial function. In fact, some approximations are commonly used for microwave filters (Butterworth, Chebyshev,...) [1]. After, the initial element synthesis part, the lumped elements are then transformed into distributed elements (transmission line). Practically, the distributed structures are obtained from LC equivalent prototypes by using distributed equivalents of the lumped reactance. There are other filters designed by exploiting low-pass prototype and classic network theory based on specific transforms developed for distributed structures. It should be noticed that, the rejection is an important parameter in the design approach [2-12], in fact improving it can be obtained by increasing the polynomial function order.

Because of its easy fabrication, low cost and miniature size, planar microwave filters especially low pass filters are widely used in microwave communication systems. The traditional approach to design a microstrip low-pass filter is generally based on shunt stubs or stepped impedance lines. However, filters using this kind of topologies need a large size to obtain a low cutoff frequency. This can be attributed to the physical size of one section of the filter structure, which is comparable to a half-wavelength of the design frequency. Recently, researchers and designers are in the pursuit of compact filters with low insertion loss and high rejection. For this reason, several topologies and design techniques to develop low-pass filters have been proposed in literature.

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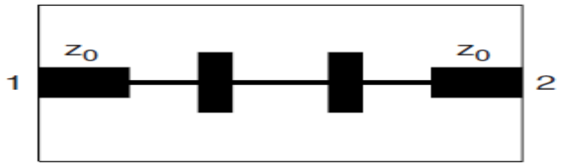
In this paper, a novel design of low pass filter using ring resonator associated with open stubs is proposed. This low cost filter is very compact and presents interesting electrical performances.

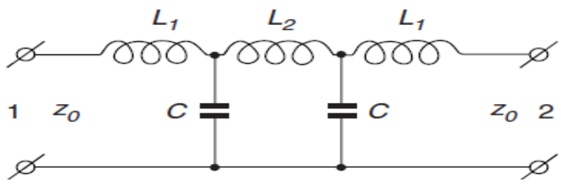
To validate the proposed circuit, ADS Agilent solver was used in order to verify the simulation results and to perform all the parametric studies. The circuit was fabricated and measured, a good agreement between the simulation results and the measured ones was obtained, which confirms the design and the optimization method used in this work.

II. DESIGN PROCEDURES

TEM structures microstrip lines are ideal for LPFs. To design a microwave LPF, we have to start our study by using the idealized lumped-element circuit. Fig.1 presents the relationship between a microstrip low pass filter and a low pass filter prototype [13]. A series inductance is replaced by a short section of a high-impedance transmission line. And a shunt capacitor is equivalent to a low-impedance transmission line.



(a)



(b)

Fig.1. Stepped impedance microstrip LPF: layout of 5th order filter (a); equivalent circuit (b).

If the length ℓ of a high-impedance section is less than λ/8. Where the electrical lengths of the inductor sections to be calculated as [1]:

$$\beta\,\ell = \frac{L\,R_0}{Z_h} \quad \text{(inductor)} \qquad (1)$$

and the electrical length of the capacitor sections as [1]:

$$\beta\,\ell = \frac{C\,Z_l}{R_0} \quad \text{(capacitor)} \qquad (2)$$

Where R_0 is the filter impedance, L and C are the normalized element values. In addition, the actual values of Z_h and Z_l are usually set to the highest and lowest characteristic impedance that can be practically fabricated.

But not always simple to achieve a LPF by using the equivalent between microstrip lines and lumped elements, therefore, the design of a compact low pass filter is based often on optimization, tuning and numerical methods.

To validate the proposed LPFs, we have conducted the first study by using Momentum integrated in ADS, this electromagnetic solver is based on the method of moments. We have started our study by optimizing the ring microstrip topology in order to have a low pass behavior taking into account the miniaturization of the final circuit and to obtain at the end good performances in term of insertion loss and the attenuated band. After many series of optimization, we have obtained the LPF structure depicted in Fig.2.

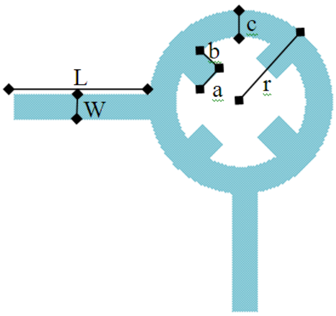


Fig.2. The configuration of the proposed low pass filter.

As mentioned in Fig.2, the final circuit is composed from a microstrip ring associated to four stubs and two identical microstrip feed lines. The different stubs and the inner and outer radius permit to adjust the bandwidth and to enlarge the

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attenuated frequency band. The dimensions of the optimized LPF are listed in Table 1.

Table 1. Dimensions of the filter in mm

L	W	a	b	c	r
8.55	1.55	1.82	1.82	1.65	5.7

As shown in Fig.3 we have a LPF with a cutoff frequency of 2 GHz and an insertion loss around -0.12 dB and a wide attenuated band. To study the electric field, Fig.4 presents the Electric Field at 1GHz in the bandwidth, which presents that we have a flow of energy between port 1 and 2. In addition, the attenuation of energy for the frequency at 5 GHz illustrating the attenuated band.

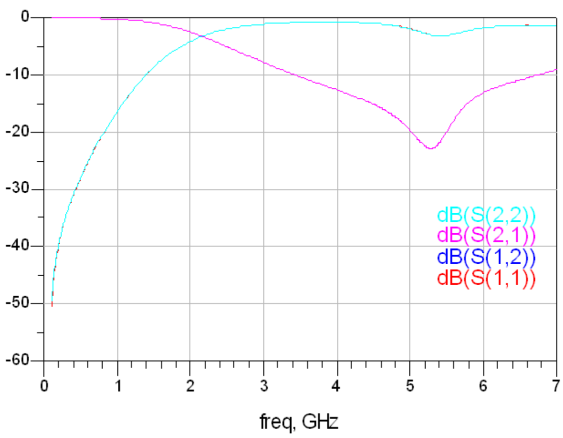
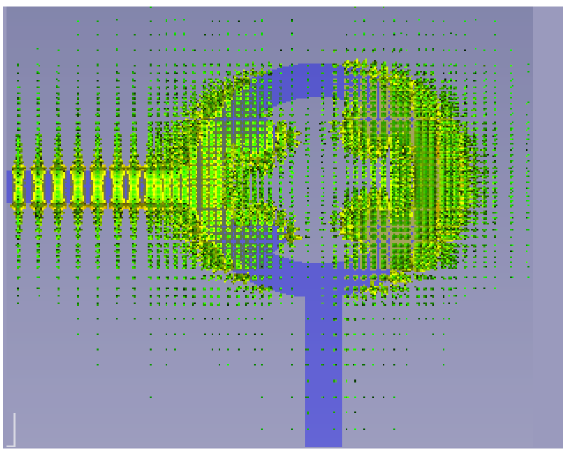
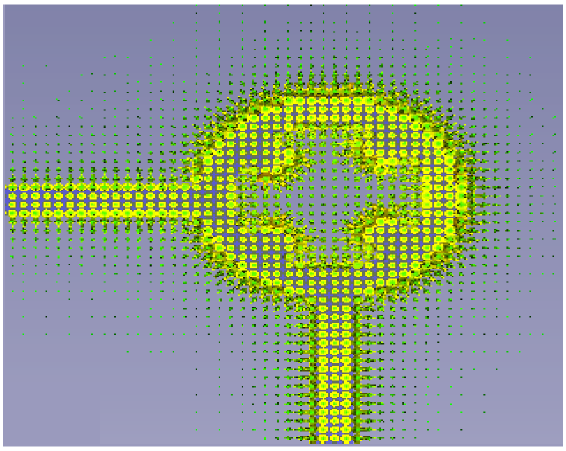


Fig.3. S-parameters versus frequency.



(a)



(b)

Fig.4. The E filed of the proposed LPF: (a) at 5 GHz and (b) at 1 GHz.

Our design approach is based on optimization and electromagnetic characterization of the low pass filter. Therefore, it was necessary to achieve various parametric studies to obtain the desired frequency response. For that, the proposed low pass filter was simulated under different values of the length of the open stubs associated to the ring resonator. The obtained simulated results are illustrated in the Fig.5.

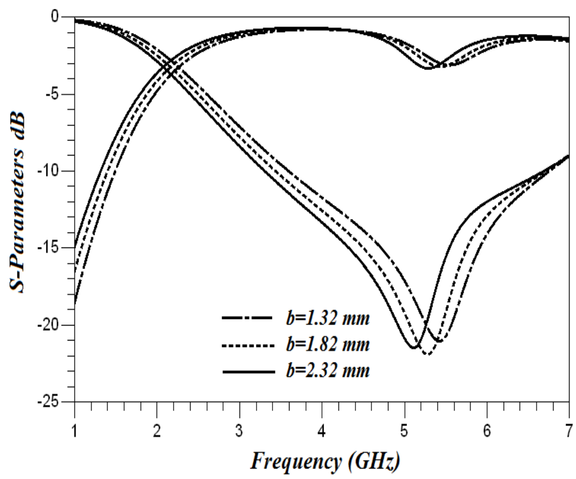


Fig.5. Frequency response of the proposed low pass filter under different values of the length of open stubs associated to the ring resonator.

We can clearly observe that, this geometrical parameter influences significantly the frequency response of the proposed filter. In fact, increasing

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the value of open stubs length from 1.32 mm to 2.32 mm set the cut-off frequency at higher frequencies and enlarges the passband bandwidth. In other hand, the variation of this parameter can influence the location and the attenuation of the transmission, which will enlarge the attenuation band and suppress the unwanted resonant frequencies.

III. FABRICATED DEVICE AND MEASUREMENT

After the validation of the proposed LPFs, we have passed to fabrication. Fig.6 presents the photograph of the achieved filter having a volume of 25x25x1.6 mm^3. This circuit was tested by using a VNA of R&S using 3.5 mm calibration kit.

Fig.6. A photograph of the proposed fabricated LPF.

As shows in Fig.7, the tested LPFs present a good agreement between simulation and measurement results. The measured insertion loss in the bandwidth is around -0.22 dB with a cutoff frequency of 2.13 GHz and a wide attenuated frequency band.

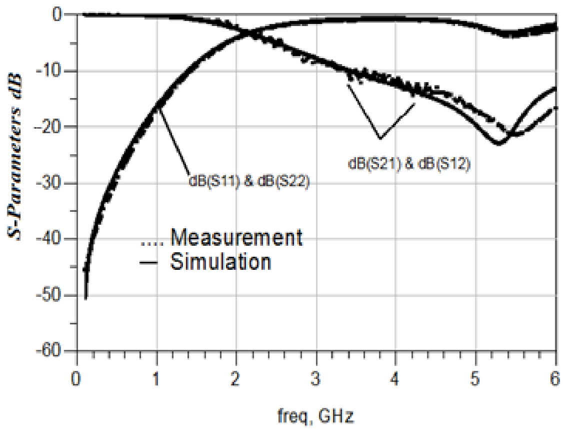

Fig.7. Simulation and measurement results comparison of the S-parameters.

After the validation of the proposed structure into simulation and realization, a comparison between the realized filter and other low pass filters proposed in literature is introduced.

As mentioned in Table 2, we can clearly observe that the proposed filter presents remarkable electrical performances with low insertion loss, large band stop with good rejection and compact size with 25x25 mm^2.

Table 2. Comparison between the achieved filter and other filters proposed in literature.

Published literature	Circuit size (mm^2)	Cut off frequency (GHz)	$\|S_{12}\|/\|S_{11}\|$ (dB)	Stop band range	Average S_{21}-magnitude of stop band (dB)
[14]	50x17	0.9	0.2/20	Up to 3 GHz	20
[8]	20x20	2.33	0.15/15	Up to 7 GHz	10
[15]	54x40	1.2	0.1/15	Up to 3 GHz	20
[16]	25.6x9.78	3.12	0.3/11.5	Up to 19 GHz	20
[17]	91x17	1	0.1/30	Up to 2 GHz	15
Proposed filter	25x25	2	0.13/15	Up to 7 GHz	10

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IV. CONCLUSION

This paper has presented the design of a new simple compact microstrip LPF based on a ring configuration. The final circuit is validated by using optimization methods and tuning techniques. This structure is miniature and suitable for GSM, DCS and UMTS application due to the cutoff frequency, which is around 2.13 GHz. The LPF fabricated structure presents good performances in term of insertion loss and a wide stopband. The different steps followed to achieve such circuit can be used to match this configuration to other applications.

ACKNOWLEDGEMENT

We thank Mr. Angel Mediavilla Sanchez professor & Director of DICOM Laboratory in Cantabria University in Spain, for allowing us to use all the equipment and electromagnetic solvers available in his laboratory.

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